MR. CLEAN BOARD

By

Thomas Furlong

James Krein

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TA: Soumithri Bala

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Abstract

This final report discusses the accomplishments, challenges, and future improvements of Mr. Clean Board. Mr. Clean Board is an autonomous car used to clean a whiteboard for a professor during or after class. Mr. Clean Board successfully attaches to the board with powerful magnets and uses infrared (IR) lighthouses to detect the edges of the whiteboard. This document will provide insight into the major subsystems and design components which enabled Mr. Clean Board to perform its task of erasing the board.

Contents

1. Introduction

In many of today's academic and professional settings, whiteboards and blackboards are commonly used. In collegiate environments, professors often write their lecture notes on these boards. During class time, the professors must balance their time between writing notes on the board as well as addressing the class directly. Often, the board space is limited causing the professor to take time out of the lecture to erase the board. Furthermore, it is a common courtesy that the board is cleaned at the end of class. Sometimes, the professor overlooks cleaning the board because they are caught up interacting with their students at the end of class leaving this task for the next class's professor.

With the inconveniences discussed above in mind, Mr. Clean Board was created to make erasing the whiteboard more convenient. Mr. Clean Board is useful because professors now regain this time spent erasing the board and can utilize this time to assist students in class, or after, and additionally, allows professors to easily erase the board at the end of class.

When designing Mr. Clean Board, the engineering problems that emerged are listed as follows: finding reliable means to keep the car attached to the whiteboard, finding reliable means to detect the edges of the board in order to prevent the car from driving off the board, and finding reliable means to erase the board in its entirety while doing so in a swift and efficient manner. In addition to these engineering problems, portability of the project and cost of the design were also considered.

Chapter two discusses the design of the overall system as well as the subsystems that work together to solve the engineering problems. Each system and its integration into the design is described along with the individual components that comprise the system. In chapter three, the requirements for each system and its components are described along with the verification to prove if the component passed or failed its requirement. An appendix is provided to provide more detailed requirements and verification. Chapter four will analyze the estimated cost of labor and parts needed to make the prototype version of Mr. Clean Board as well as a commercial version of Mr. Clean Board. Chapter five discusses the accomplishments and challenges that Mr. Clean Board faced as well as improvements that can be made going forward.

Overall Mr. Clean Board met the requirement of erasing the board at a fast pace and met the requirement for edge detection on the board; however, Mr. Clean Board failed to erase the entirety of the board which is detailed in the final chapter.

2 Design

While several solutions for automatic whiteboard erasing exist, Mr. Clean Board's design takes a different approach. Most of the currently proposed solutions involve mounting a frame around the whiteboard that holds an arm connected to a giant eraser which slides back and forth across the board. The design of Mr. Clean Board is meant to be more portable than these solutions as all the components are magnetic and can easily be removed from the board and placed on another if necessary. This portability allows for Mr. Clean Board to be integrated into already existing whiteboards without the much hassle.

This chapter discusses both the design procedure and the design details for Mr. Clean Board. This chapter is comprised of several sections each detailing a major subsystem and its components. The design decisions for each component are discussed in the relevant subsections along with their technical information.

The major subsystems of the car include the power system, motor control, control systems, and the outside signals. A high-level overview of how these systems interact is shown in Figure 1.

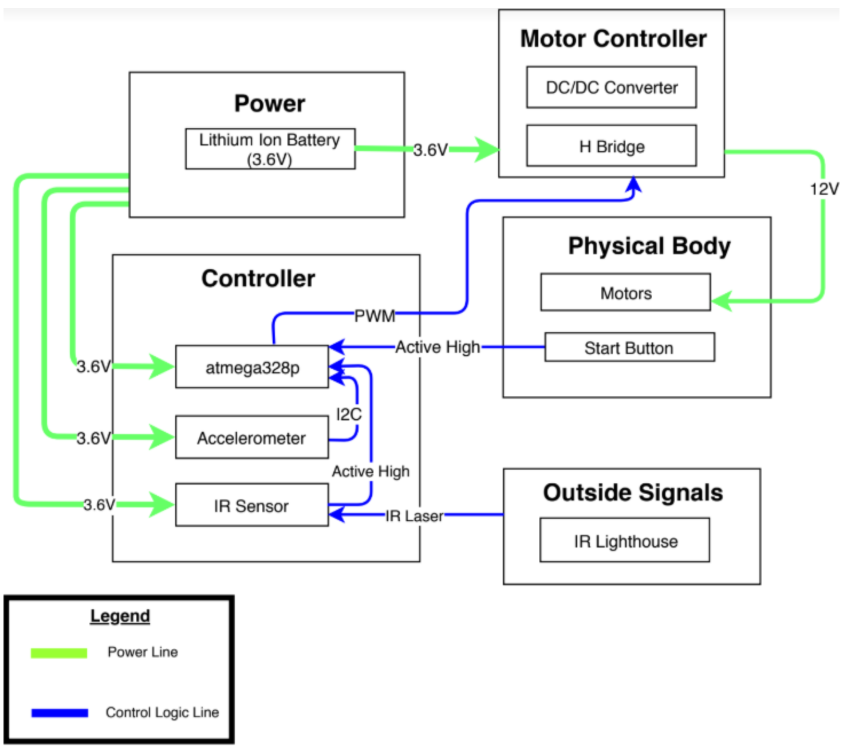

Figure 1. Block Diagram of Mr. Clean Board

2.1 Power

The second major component is the power system. The design of the power system allows for all components, except for the outside signals (see section 2.5), to draw power from this system. The power system accounts for the voltage ranges of all components and keeps them within the valid operating range. The power system design also contains enough capacity to keep the car continuously running for a couple hours and contains recharging capabilities. The design details of the individual components are described the following sections.

2.1.1 Batteries

Since the car's main function is to erase a whiteboard, batteries were chosen to be the main power source. Batteries provide a more convenient way to power the car versus a wall outlet since a long wire would have to run from the outlet to the board so that the car could drive freely across the board. The wall outlet method also provides problems because the wire could accidentally be stepped on causing the car to be yanked from the board. The issue with batteries comes forth in lower power outputs and limited capacity.

Mr. Clean Board possesses two lithium-ion batteries. The batteries chosen were the LGDBHG21865 and feature a nominal voltage of 3.6 V, a maximum current output of 15 A, and a battery capacity of 3,000 mAh. Two battery holders were soldered onto the printed circuit board (PCB) to provide the power for the rest of the circuit. The holders allowed for easy removal of the batteries which is useful for when the batteries needed recharging. A standard wall outlet lithium-ion battery charger was used for recharging the batteries; however, our PCB contained functionality to integrate a USB charger directly on the car. For actual production models of the car having a USB charger would be more convenient over the wall charger, but for the prototype testing could not have taken place while the batteries were charging.

2.1.2 DC/DC Boost Converter

The nominal sate of the battery provides enough power to supply the microcontroller and sensors; however, the voltage output of the battery is not enough to supply the 12 V required by the motors. A boost converter is used to step up the 3.6 V to the required 12 V needed by the motors.

The 12 V was chosen because the motors achieve their maximum RPM at this voltage. The chip used in the design was the TPS55340. A schematic of the implementation on the PCB is shown in Figure 2. Two inductors in series smooth the current going into the boost converter while a capacitor bank smooths the voltage going to the motors. The design of this circuit was aided by references provided by Texas Instruments [1]. The boost converter chip turns on with a control signal from the microcontroller allowing for the boost converter to be toggled on and off. This design choice allows the converter to be more energy efficient by turning off the converter to conserve energy when the car is in rest mode. The boost converter voltage was fed into the H-bridge which is why it appears under motor control in the block diagram.

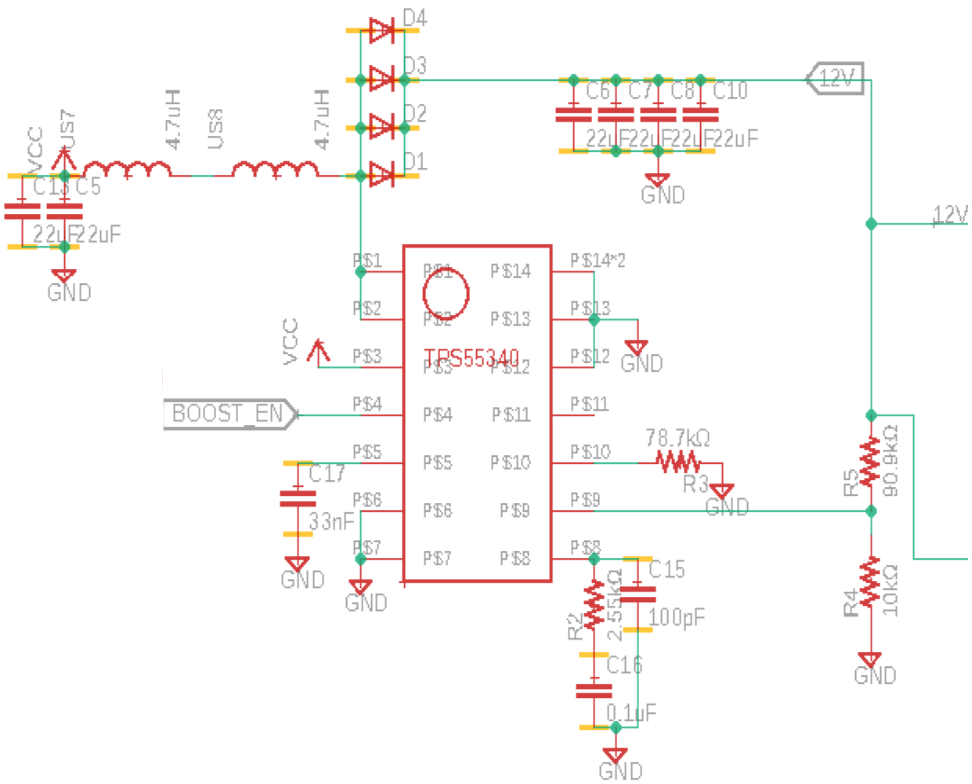

Figure 2. Boost Converter Schematic

2.2 Motor Control

The car was able to drive intelligently on the board using the motor control systems. This system was divided into two major parts. First, the DC/DC converter was crucial to sending 12 V to the H-Bridge. The H-bridge then used the 12 V from the boost converter along with PWM signals being sent from the microcontroller to create the output to the motors.

2.2.1 H-Bridge

The H-Bridge is responsible for routing power to the motors in a controlled manner. The H-Bridge chip used in the design is the DRV8844. The schematic is shown in Figure 3 which was aided by the reference designs provided by Texas Instruments [2]. The chip has four input channels allowing each motor to be driven both forward or backward. Driving each motor individually was essential for completing the turns needed to properly drive the control the car on the board. The H-Bridge also interfaced with several control pins tied to logic pins on the microcontroller. These pins allow the H-Bridge to be turned on and off in a similar fashion to the boost converter to achieve better energy efficiency. Two system state pins are also connected to the microcontroller to monitor faults or shorts through the H-Bridge.

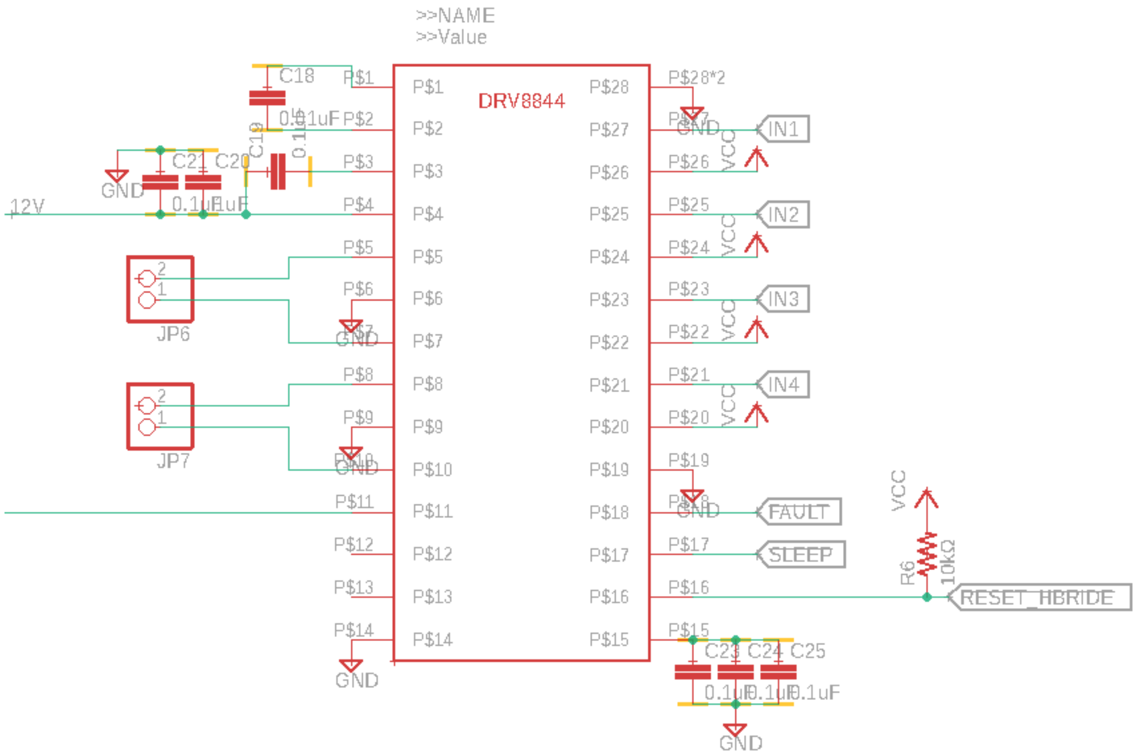

Figure 3. H-Bridge Schematic

2.3 Control Systems

The control system is the main processing unit for the car. It includes all the outside signals as well as the microcontroller which monitors all the inputs. The outside signals include an accelerometer to monitor the tilt of the car as it drives, IR receivers to detect edges of the board, and push buttons to start the car and run test cases. The embedded software on the microcontroller is what allows the car to have a diverse set of actions as the car detects different environment settings.

2.3.1 Microcontroller

The microcontroller on the car is the Atmega328pb. This is an 8-bit processor that has a reduced instruction set which is beneficial for embedded applications. The clock divider fuse bits were changed allowing the microcontroller to run on an 8 MHz internal clock. The default internal clock was 1 MHz, but this was problematic because the car needed to read the sensors at a faster rate. One of the major roles for the microcontroller is generating the PWM’s that control the motors. These PWM’s are written by the microcontroller into the H-Bridge to drive each motor in a desired direction and speed. The PWM signal that is written to the H-Bridge is determined by the software. An overview of the software system is shown in Figure 4. The car waits in a sleep state to conserve energy until a push button is pressed. From there, the car enters a generic control loop that monitors the accelerometer data as well as the IR sensors and controls the car accordingly.

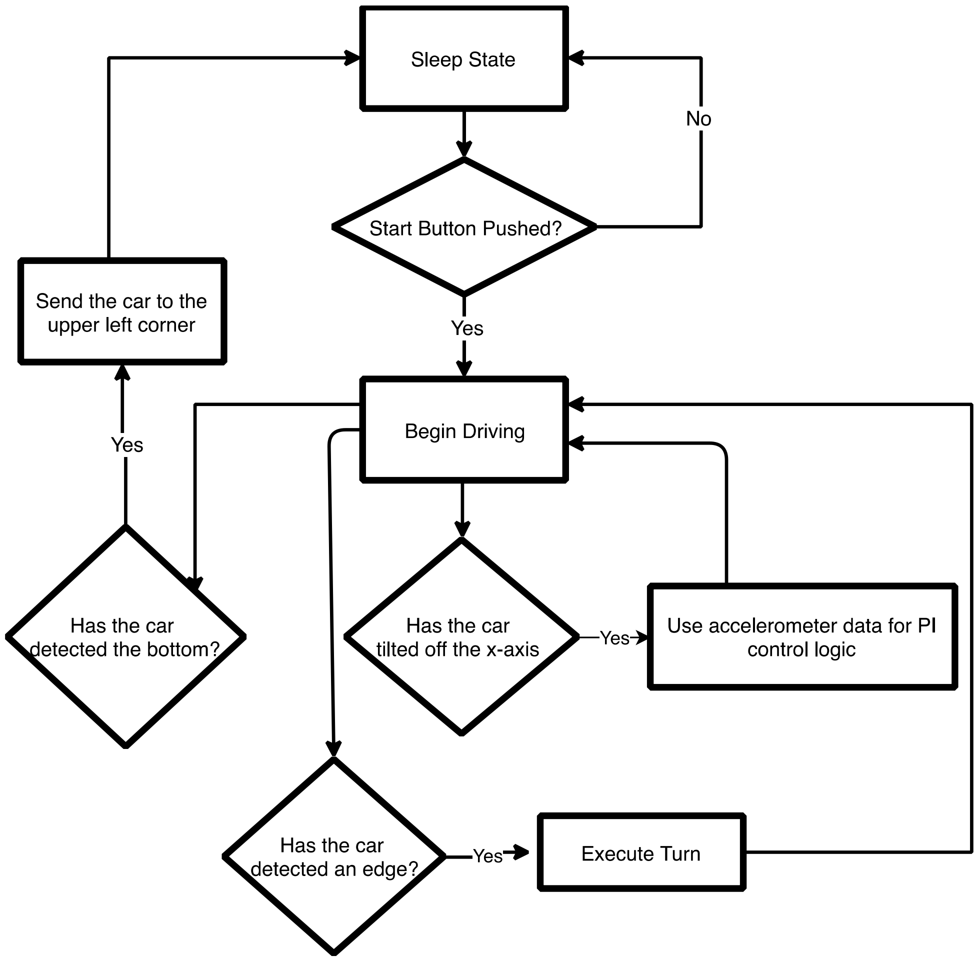

Figure 4. A General Flowchart for the Software

2.3.2 Proportional Integral (PI) Control

The microcontroller was programmed to run a PI control loop that monitors the accelerometer data. This control loop follows Equation 1. In Equation 1, $e(t)$ is the tilt of the car off the x-axis, while the integral of $e(t)$ is the tilt accumulated over time. K and C are tunable parameters to weight either the current tilt or total tilt more heavily. This equation is used to determine the speed of the wheels as the car is driving horizontally on the board. Having a control loop is necessary because of the tilt the car experiences from gravity and imperfections in the motors.

$$Speed = (K \cdot e(t)) + (C \cdot \int e(t)dt) \quad (1)$$

2.3.3 Accelerometer

The car uses the accelerometer to determine the tilt off the x-axis of the board as it is driving. Without this sensor, the car would not be able to drive in a straight line while cleaning. The design uses the Adafruit 9 Degrees of Freedom board. The original design called for the use of just the accelerometer but the soldering pins for the chip were very small and could not be soldered correctly onto the PCB. The board uses I2C connection to communicate with the microcontroller. At the 8 MHz clock the accelerometer can provide 13 data points per second of the cars rotation. This high rate of data acquisition allows the PI control to adjust the speeds of the wheels at a higher granularity.

2.3.4 Push Buttons

The car has push buttons with variable functionalities. The first button was the reset button that reset the chips on the PCB as well as the embedded software. This button was useful for restarting the car in case of run time issues. The second button was the clean button that started the car's cleaning sequence. The third button was used to implement different tests to inspect various sensor data.

2.3.5 IR Receivers

The IR receivers on the car allow it to detect the IR Lighthouse signals around the board. The receivers used for this were the TEST2600 and the circuit for the receivers is shown in Figure 5. In Figure 5, a higher resister value results in a more sensitive receiver. Multiple resistors values were tried, but a resistor value of 22 kΩ had the best results. This resistor value allows the car to detect the IR Lighthouse from two meters away. There was also a TSOP38238 IR receiver on the car. This receiver paired with a IR remote that allows the car to turn on and start cleaning with the press of a remote button.

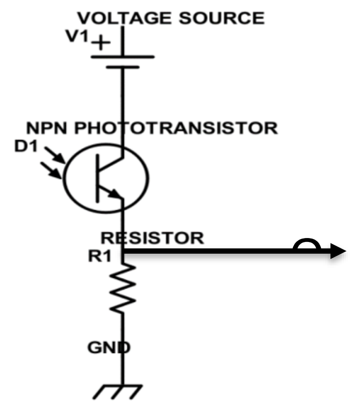

Figure 5. IR Receiver Circuit Schematic

2.4 Outside Signals

The outside signals come from the IR lighthouses. These signals mark the boarders of the board by making a grid of IR light. The IR receivers on the car pick up these signals and can adjust the car's course accordingly. There are four lighthouses used to cover the board and their orientation on the board is shown in Figure 6. Four lighthouses were chosen because this design allows for the use of only two IR receivers on the car.

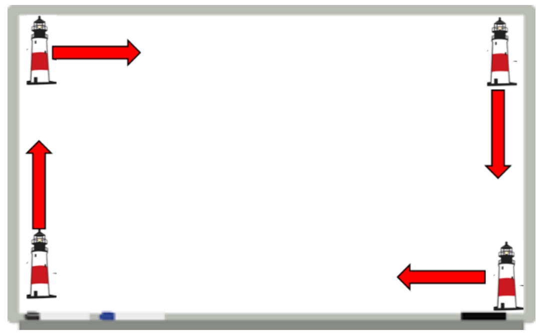

Figure 6. IR Lighthouse Orientation

2.4.1 IR Lighthouses

The IR lighthouses are the emitters that magnetically attach to the board and create the board's boundaries. The lighthouses use the VLSY5940 IR emitter as the source of the IR light. The emitter produces light at the 940 nm wave length. They each have an independent 3V battery to power the lighthouses and have a run time of around 18 hours. The schematic for the lighthouses and an image of a lighthouse is shown in Figure 7.

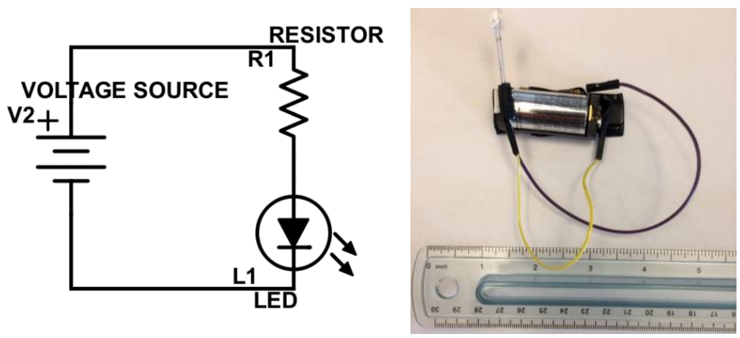

Figure 7. IR Circuit Schematic (Left), Image of IR Lighthouse (Right)

When considering different IR emitters for the lighthouses, the half intensity angles were investigated. Since the IR receiver's circuit is highly sensitive, the potential for detecting the IR lighthouse signal to soon was an issue. While using an IR laser would eliminate this issue the lasers were found to be too expensive for our design goal; therefore, using a very narrow beam IR emitter helps mitigate this issue. The potential issue of having a wider beam width is demonstrated in equations 2 and. The equations calculate the distance away from the edge of the board an IR signal could be potentially detected. Equation 2 calculates the distance for a half intensity angle of 17° and Equation 3 calculates the distance for a half intensity angle of 3° [3].

$$\tan(\theta) = \frac{3y}{x} \Rightarrow 3y tan(\theta) = x = .9171\ ft * \frac{12\ in}{1\ ft} = 11\ in \quad (2)$$

$$\tan(\theta) = \frac{3y}{x} \Rightarrow 3y tan(\theta) = x = .262\ ft * \frac{12\ in}{1\ ft} = 1.88\ in \quad (3)$$

3. Design Verification

The verification stage of the project was important to check the functionality of each major subsystem for the car. The following sections describe the verification and results of the major requirements needed to guarantee the success of the project. A more detailed list of requirements and verification can be found in Table 3 in Appendix A.

3.1 Power Systems Verification

3.1.1 Car Run Time

In Table 3, requirement 1b is listed. Two hours of continuous use is a design requirement because the car should be expected to run several times before needing a charge. There were two batteries used that had a nominal voltage of 3.6 V and a capacity of 3,000 mAh. The average PWM of the motors is 70% and each motor is rated at 7 W. As shown in Equations 4 and 5, the total run time is found to be 2.2 hours. The power consumption of the chips on the car were excluded in this analysis because of their menial power requirements.

$$(2\ Batteries) \times 3.6V \times 3{,}000mAh = 21.6\ Wh \tag{4}$$

$$\frac{21.6\ Wh}{(2 \times 7W) \times 0.70} = 2.2\ hours \tag{5}$$

3.1.2 Battery Output

Table 3 also lists requirement 1a. The 1.5 A was chosen because of the load current of both motors together is 1.2 A. This gives some room for the variation in the current draw from the motors. The valid operating range of the motors was also noted to fit the required range. The max of 4.2 V was the state of a fully charged battery. Additionally, the motors would not spin properly when the voltages of the batteries dropped below 2.8 V. These voltages were measured with a multimeter throughout testing.

3.2 Motor Control Verification

3.2.1 Boost Converter Requirement

Table 3 lists requirement 3b. This requirement is necessary because as the batteries are used, the output voltage changes. With this change, the boost converter must be able to constantly output a high enough voltage for the motors. The boost converter has a voltage divider circuit shown in the lower right of Figure 2. Equation 6 with $R_1 = 90.9\ k\Omega$ and $R_2 = 10\ k\Omega$ produces Equation 7. The theoretical output is shown to be 12.4 V. The measured output was 12.14 V and was taken for various voltage levels of the batteries to guarantee consistency.

$$V_{out} = 1.229V \times \left(\frac{R_1}{R_2} + 1\right) \tag{6}$$

$$V_{out} = 1.229V \times \left(\frac{90.9\ k\Omega}{10k\Omega} + 1\right) = 12.40061V \tag{7}$$

3.2.2 H-Bridge Output Requirement

Table 3 lists Requirement 3a. The H-bridge must take in the PWM from the microcontroller and couple that with the output of the boost converter to control the motors in specific directions. This requirement was necessary because the motors must be controllable by the microcontroller. To verify this, Figure 8 shows the PWM output of the microcontroller and the output PWM of the H-Bridge to the motors. Both signals were measured with an oscilloscope as the car was stationary. The output of the microcontroller reaches 1.76 V while the H-Bridge output reaches 7.5 V. This was a 70% duty cycle. The noise shown in Figure 8 is suspected to be switch ringing from the inductors.

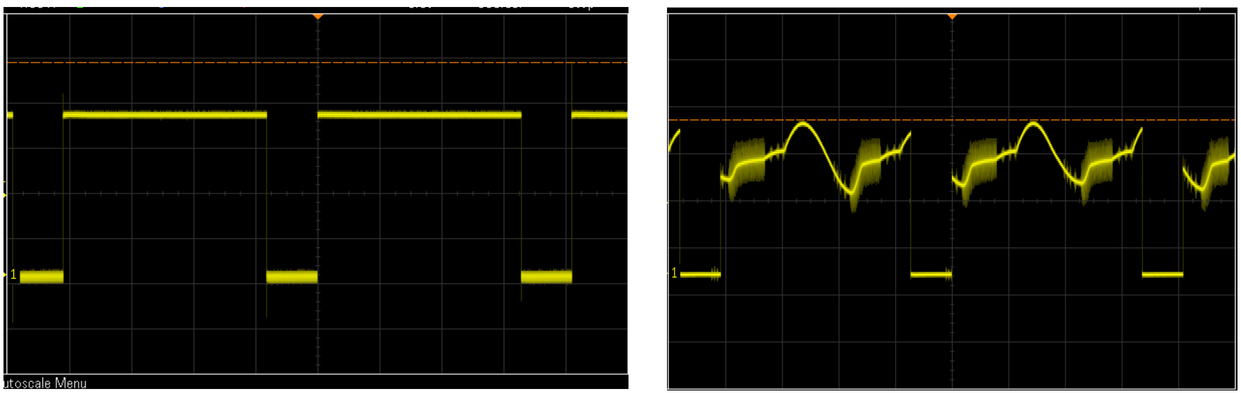

Figure 8. PWM Output from Microcontroller (Left), PWM Output from H-Bridge (Right)

3.3 Control Systems Verification

3.3.1 Software System Requirement

Table 3 lists requirement 2e. Being able to drive in a straight line is essential for the proper cleaning routine of the car. To verify this requirement, the PI control was implemented, tested and optimized. The tunable parameters were changed until a mostly straight path was produced by the car. The car was able to drive in a straight line with minimal swaying, so the requirement was met.

3.3.2 Accelerometer Requirement

Table 3 lists requirement 2b and 2c. Being able to communicate quickly and accurately is important for the PI control to update the speed of the motors. At the 8 MHz internal clock, the microcontroller can receive 13 samples from the accelerometer a second. The data it receives is three floating points and each floating point is 32 bits. Putting this together Equation 8 is formed to realize a total rate of 1248 bits per second.

$$3 \times 13 \; samples \; per \; second \times 32 \; bits \; per \; sample = 1{,}248 \; bits \; per \; second \qquad (8)$$

The accelerometer must also report the tilt of the car to the hundredths place. This was necessary because .01 radians ≈ 0.6 degrees. At the speed the car drives, a gentle continuous tilt of .01 radians would send the car a few inches off its original path. As shown in Figure 9, the accelerometer does report the tilt with the granularity of the hundredths place. The accelerometer data was serial printed to a text file which was entered into an Excel graph.

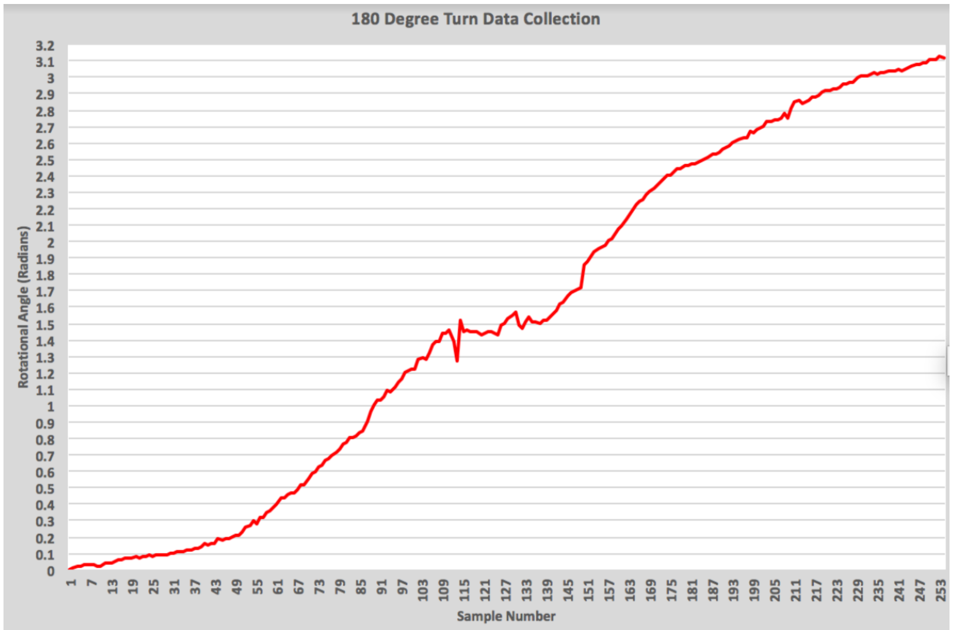

Figure 9. Accelerometer Granularity graph

3.4.1 IR Lighthouse Requirement

3.4.1 IR Lighthouse Requirement

Table 3 lists requirement 4a. This requirement was to guarantee the car could detect the IR signal from over six feet away which was the board size that the car was expected to run on. Figure 10 shows the graph of the analog signals that the microcontroller read in a test by aiming the IR emitter at the receiver from two meters away. The spike shown in Figure 10 happens when the emitter enters the viewing angle of the receiver.

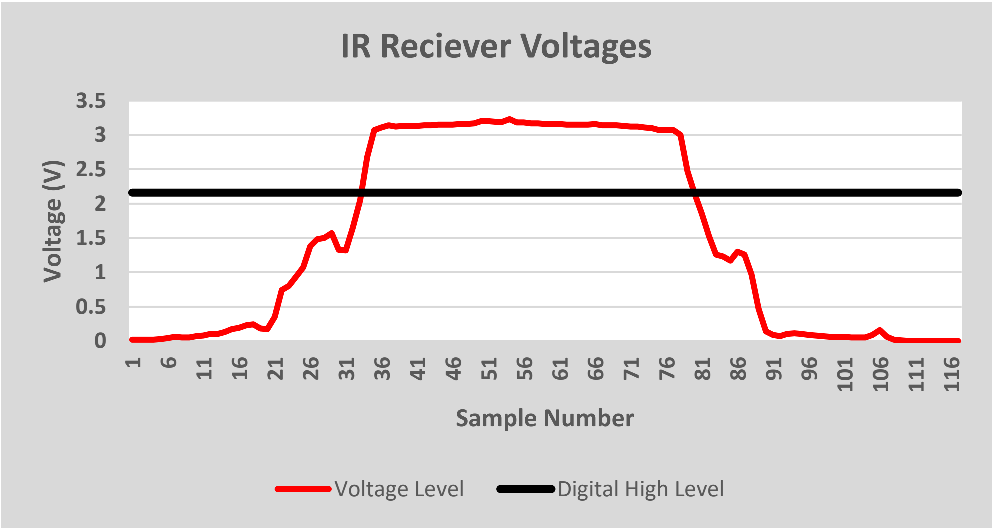

Figure 10. IR Receiver Voltage Levels

4. Costs, Labor, and Schedule

4.1 Parts

Table 1 Parts Costs

Part	Manufacturer	Retail Cost ($)	Bulk Purchase Cost ($)	Actual Cost ($)
Atmega328pb	Atmel	1.39	1.16	Free
TPS55340	TI	3.75	2.76	Free
DRV8844	TI	4.08	3.00	Free
TEST2600	Vishay	1.06	0.58	Free
VLSY5940 IR	Vishay	1.50	0.75	Free
Push Buttons	Sparkfun	0.95	0.95	Free
Resistors, Capacitors, Inductors	TI	3.27	2.89	Free
Accelerometer	Adafruit	14.95	11.96	18.45
Car Battery	LG	7.00	6.39	15.23
Car Battery Holder	BLM	5.86	5.86	6.03
Lighthouse battery	Energizer	1.45	1.45	2.86
Lighthouse battery holder	Keystone Electronics	0.99	0.99	1.89
Motors	UX Cell	15.98	15.98	32.07
Wheels	BQLZR	9.18	9.18	10.18
L Bracket	UX Cell	5.90	5.90	6.30
PCB	PCB Way	23.87	23.87	23.87
Acrylic Body	Home Depot	20.34	20.34	20.34
Eraser	Clorox	2.58	2.58	2.58
Magnets	X-bet	13.29	13.29	Free
Total		**153.48**	**145.97**	**139.80**

4.2 Labor

The cost for labor is calculated based on the average starting salary for students graduating with a bachelor's degree in computer engineering and electrical engineering. The average starting salaries are those reported in 2016 - 2017 by UIUC graduates [4]. The calculation is also based on working 10 hours per week for 13 weeks, which is the number of weeks from the projects approval until its required completion. The machine shop was not used for this project. The calculation is performed below in Equation 9.

$$2 * \left(\frac{\$96{,}518}{year} \times \frac{1\ year}{52\ weeks} \times 13\ weeks \times \frac{10\ hours}{40\ hours}\right) = \$12{,}01 \tag{9}$$

4.3 Schedule

Table 2 Schedule

Week	Task	Person
10/8/2018 10/15/2018	Rough test of magnets on model car	Jimmy
	Order IR receivers and transmitters	Thomas
10/22/2018	Work on PCB design	Both
	Order the rest of the materials	Jimmy
10/29/2018	Program microcontroller with I/O and motor control logic	Thomas.
	Begin soldering with the first revision of the PCB	Jimmy
11/5/2018	Have chassis of car to begin mounting wheels and motors	Jimmy
	Attach sensors and have fully programmed microcontroller	Thomas
11/12/2018	Begin designing the second version of the PCB	Both
	Debug motor control logic	Both
11/19/2018	Work around PCB design issues and attempt to design a new one	Jimmy
	Enjoy Thanksgiving break	Both
11/26/2018	Put the car together and double check every functionally	Thomas
	Get ready for mock presentation	Both
12/3/2018	Make slide deck for final presentation	Both
	Start the final paper	Both

5. Conclusion
Overall Mr. Clean Board proved to be a success. Even though Mr. Clean Board was unable to erase the entirety of the board, a little mechanical ingenuity and fine tuning could fix this issue. The accomplishments, challenges, ethics, and future work of Mr. Clean Board are discussed in this chapter.

5.1 Accomplishments
Mr. Clean Board's accomplishments are described as follows: successfully attached to the board via magnets, successfully completed the erasing path across the board in under 2.5 minutes, successfully detected the edges of the board via the IR lighthouses, and successfully drove across the board in a reasonable straight line. These successes show that with a little more time for fine tuning and some mechanical improvements Mr. Clean Board could become a viable option for conveniently erasing the board.

5.2 Challenges
The challenges Mr. Clean Board faces are driving in a near perfect line, erasing the whole board, and detecting exact remote button presses.

The PI control worked well to an extent, but the car still experienced some oscillatory motion as it was driving across the board. This can be solved with some more parameter tuning, or perhaps a faster microcontroller to allow more calculations to be made per second.

The reason Mr. Clean Board is unable to erase the whole board is because the turning radius of the car is wider than the erasing radius. This leaves gaps of the whiteboard not erased. This issue stemmed from not having enough pressure to firmly apply the erasure on the board at the larger radius. A larger eraser may assist a little in closing the gaps, but if the pressure on the outskirts of the eraser is too small the larger eraser will provide little to no extra effect.

The signals from the remote control could be detected; however, the exact button pressed could not be determined as the interrupt system used to set up the receiver did not work correctly with the microcontroller. Knowing which button on the remote is pressed would allow for only designated remotes to work with the car instead of any remote-control signal being sent in the car's general detection.

5.3 Ethical considerations
Potential ethical concerns follow the ninth code in the IEEE Code of Ethics: "to avoid injuring others, their property, reputation, or employment by false or malicious action" [5]. This project could possibly injure others in a couple scenarios. If the robot loses traction to the board and falls to the ground the robot could potentially injure the foot. Since it is a moving object, it could also collide with the user's hand while they are writing on the board. Once the final attaching mechanism was in place, the car never fell of the board. The only time the car would come off the board is in the event an obstruction blocked its path and was able to overcome the magnetic force keeping it to the board.

Another safety hazard could be eye-damaging effects caused by IR light exposure. Our design will alleviate any potential issues since the IR emitters being used would be low power and in the near infrared range (approximately 940nm). None of the emitters will be pointed in the direction of people, but instead will be forming a square around the board. The IR emitters and detectors will be very similar to ones used for things like wireless remotes and other everyday applications. If one does not stare the try to look at the laser directly with their eye no harm should come.

5.4 Future work

The future work for Mr. Clean Board is directly related to the challenges. The PI control could be improved upon to ensure the car erases the board as efficiently as possible. By not driving in a straight line the car may be skipping over sections of the board or erasing the same section of the board twice. The other issue to fix would be the erasing mechanism. If the erasing mechanism can be extended to be the same width as the turning radius of the car, then more of the board can be erased without having to tweak how the car turns. The last portion of future work involves getting the remote to interface with the microcontroller. If this feature is implemented, then Mr. Clean Board can achieve sectional erasing which would allow the professor to begin erasing one section of the board while writing on a different section.

References

[1] "TPS55340 Integrated 5-A Wide Input Range Boost/SEPIC/Flyback DC-DC Regulator." *Texas Instruments*, 12 January 2015, www.ti.com/product/TPS55340

[2] "DRV8844 Quad ½-H-Bridge Driver IC." *Texas Instruments*, 9 May 2016, www.ti.com/lit/ds/symlink/drv8844.pdf

[3] "High Speed Infrared Emitting Diode, 940 nm, Surface Emitter Technology." *Vishay Semiconductors*, 29 May 2015, www.mouser.com/datasheet/2/427/vsly5940-537303.pdf

[4] Services, Engineering IT Shared. "Undergraduate Degree History." *Fields of Specialization :: ECE ILLINOIS*, 2018, ece.illinois.edu/about/degree-history.asp.

[5] "IEEE Code of Ethics." *IEEE - Advancing Technology for Humanity*, Ieee, www.ieee.org/about/corporate/governance/p7-8.html.

Appendix A Requirement and Verification Table

Table 3   System Requirements and Verifications

Requirement	Verification	Status (Y or N)
1. Power Requirements a. The battery must produce 1.5A of current while operating at 2.8V – 4.2V. b. The battery must be able to provide two hours of continuous use.	1. Power Verification a. Attach the motors to the battery and monitor the current and voltage levels with a multimeter. b. Attach the motors directly to a fully charged battery and make sure the run time of both motors is at least two hours.	 Y Y
2. Control System Requirement a. The logic in the microcontroller must operate with a supply voltage of 2.5V - 4.2V b. The microcontroller must read the data from the accelerometer at a rate of 9600 bits per second. c. The accelerometer must report the rotation degree off the x-axis to the hundredths place. d. The accelerometer must detect when the car has moved 3 degrees of the x-axis of the board. e. The software systems must drive the car in a straight line and turn the car when necessary.	2. Control System Verification a. After programming basic logic in the controller, connect the motors to the battery and verify the logic works properly. Also, check the Vin pin to the chip using a multimeter. b. Program the microcontroller to pull the accelerometer for a 1 second interval. Then, report the number of reads that it accomplished. c. Have the accelerometer send the chip data to microcontroller which processes the data. Then, the microcontroller sends the data to the PC which displays on a serial port terminal the rotational axis values. d. Attach the BMA255 to the microcontroller and have the microcontroller turn on a LED when the accelerometer is rotated more than 3 degrees of the x-axis. e. Monitor the behavior of the car as it drives and tweak PI control parameters to reach desired movement patterns.	 Y Y Y Y Y
3. Motor Control Systems Requirement a. The H-Bridge must work with a 60 kHz PWM generated by the microcontroller.	3. Motor Control Verification a. Program the microcontroller to produce a 60 kHz PWM that is tied to simple motor control logic that tests both motors. Verify the desired motor functionality is	 Y

b. The converter must take the 2.5V - 4.2V produced by the battery and increase it to 12V plus or minus 1 volt.	produced. b. Attach the battery to the DC to DC converter and probe the output pins with a multimeter to verify that the output voltage is between 11V and 13V. This will be tested on 4 varying battery capacity levels.	Y
4. IR Lighthouse Requirements a. The lighthouse must produce at least a 940 nm wave that can be detected at 2 meters.	4. IR Lighthouse Verification a. Purchase a IR receiver that works with the same spectrum and have the receiver drive a LED when hit with the laser. Vary the distance between the laser and receiver to ensure the signal is detected two meters away.	Y
5. Physical Body Requirements a. The push button must turn on the robot to start the cleaning sequence. b. The magnets must be able to hold the 3lb car to the board while still giving maneuverability to the car. c. The quality of the eraser should be high enough to erase the board in no more than two passes.	5. Physical Body Verification a. Have the start button connect to the microcontroller which will monitor the pin and light up a LED when the button is pressed signaling the start of the cleaning sequence. b. Attach the magnets to the car and then put the car on the board to verify that the magnets will hold the car up. Then, hook up the battery to the motors and see if the car can move in straight lines on the board. c. Write on a whiteboard varying lines of different thicknesses and have the car drive in a straight line over them once or twice. After this, verify that the line can be erased fully after the first or second pass.	Y Y N